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SENSITIVITY OF S-CAT TO SLEEP DEPRIVATION

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14. ABSTRACT Background. NASA has need of a rapid, reliable and non-invasive means to objectively evaluate the cognitive ability of astronauts to perform mission critical tasks, particularly during extended duration space flight. One such means under consideration is the Space flight-Cognitive Assessment Tool (S-CAT), a tool designed to assess cognitive performance using a set of five cognitive performance tests. The current study had multiple goals, one of which was to evaluate the sensitivity of S-CAT to fatigue induced by sleep deprivation and circadian disruption. Research Hypothesis. Since S-CAT has demonstrated sensitivity to organic neural dysfunction, it was expected to show fatigue sensitivity. Methods. Two groups of eight US military pilots (ages 30-40) were deprived of sleep for 46 hrs, over two circadian performance nadirs. In addition to S-CAT, four other cognitive performance tests were performed repeatedly during the sleep deprivation period. The S-CAT battery of tasks was performed once every six hours up to the 33rd hour while the participants were in the experimental situation. Results. For all tests, the response time measures showed the greatest effects from fatigue. Two of the five S-CAT tests, the Matching to Sample and the Math tests, exhibited significant fatigue-related decrements on response time. The Matching to Sample test and the Continuous Processing test showed effects on accuracy and percent correct. For Continuous Processing, 4 of 6 trials were affected, beginning after 23 hrs of wakefulness and lasting until 35 hours awake. Pilots appear to be somewhat less vulnerable to fatigue compared with data from other sleep deprivation experiments.

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Background. NASA has need of a rapid, reliable and non-invasive means to objectively evaluate the cognitive ability of astronauts to perform mission critical tasks, particularly during extended duration space flight. One such means under consideration is the Spaceflight-Cognitive Assessment Tool (S-CAT), a tool designed to assess cognitive performance using a set of five cognitive performance tests. The current study had multiple goals, one of which was to evaluate the sensitivity of S-CAT to fatigue induced by sleep deprivation and circadian disruption. Research Hypothesis. Since S-CAT has demonstrated sensitivity to organic neural dysfunction, it was expected to show fatigue sensitivity. Methods. Two groups of eight US military pilots (ages 30-40) were deprived of sleep for 46 hrs, over two circadian performance nadirs. In addition to S-CAT, four other cognitive performance tests were performed repeatedly during the sleep deprivation period. The S-CAT battery of tasks was performed once every six hours up to the 33rd hour while the participants were in the experimental situation. Results. For all tests, the response time measures showed the greatest effects from fatigue. Two of the five S-CAT tests, the Matching to Sample and the Math tests, exhibited significant fatigue-related decrements on response time. The Matching to Sample test and the Continuous Processing test showed effects on accuracy and percent correct. For Continuous Processing, 4 of 6 trials were affected, beginning after 23 hrs of wakefulness and lasting until 35 hours awake. Pilots appear to be somewhat less vulnerable to fatigue compared with data from other sleep deprivation experiments. Conclusion. It is likely that S-CAT will identify astronauts too fatigued to optimally perform sensitive missions.

Keywords: Sleep Deprivation, S-CAT, Cognitive Performance, Naps

SENSITIVITY OF S-CAT TO SLEEP DEPRIVATION

INTRODUCTION

The International Space Station (ISS) will permit a far greater range of human utilization in space than was ever before possible. The human challenges facing those who work aboard the ISS are numerous. Perhaps the most daunting challenge will be the subtle cognitive degradation arising from such stressors as confinement and isolation, ambient gas anomalies, circadian disruption, sleep deprivation and temperature extremes. One of the most persistent consequences of the combined stressors involved in a long duration human presence in space will be the potential to degrade the quality of sleep to below optimal restorative levels and the associated fatigue. The effects of fatigue and associated stresses of extended space flight have been documented in the past (13, 28).

The impairment of cognitive abilities produced by sleep deprivation is well known (16, 40, 3). Reaction time, memory, eye-hand coordination and accuracy are reliably affected by even a single night of sleep deprivation (27, 14). The extensive literature on fatigue effects include increased variability in motivation, work efficiency and increases in lapses of vigilance (29, 11). Another relevant aspect of fatigue is the narrowing of attention, in which the ability to switch adequately from one part of a problem to the next is impaired (7). A characteristic of fatigue, with potentially grave consequences for astronauts, is a tendency to accept increasingly greater risks in spite of the reduced cognitive ability to deal with the risks (8, 36). Similar effects on risk taking are found during the circadian nadir for body temperature (17). Circadian disruption also is known to produce a strong performance degrading effect (2, 35). Long duration space flight will involve sleep and circadian abnormalities.

Thus the ability of the astronaut to accurately and quickly respond to even simple tasks, the ability to focus on details, troubleshoot equipment malfunctions and solve complex problems, the motivation to find a solution and the ability to assess the dangers adequately are all compromised by fatigue. These are challenges that are vital to the survival of a human presence in space. A reliable means to quantify fatigue, induced by stress, sleep deprivation and circadian disruption, would allow astronauts and the ground controllers who support them a means to better manage sleep and workload requirements safely and efficiently.

There are numerous performance measures and clinical assessment tools available. NASA needs an assessment tool that has stable and rapidly obtained asymptotic performance levels that can provide reliable feedback and one that has been established in the literature to be sensitive to many of the stresses faced in long duration space missions. The Spaceflight-Cognitive Assessment Tool (S-CAT) is currently under consideration for assessing an astronaut's performance capability. It is a version of a well-established test (33), the Automated Neuropsychological Assessment Metric (ANAM). ANAM has demonstrated sensitivity to hyponatremia (15), acquired brain injury (24, 25, 26), concussion arising from sports injury (4, 5), alcohol (36) toluene exposure (32) and radiation sickness (34). It was developed to ascertain clinical levels of neuropsychological-induced performance degradation by the Office of Military Performance Assessment Technology (OMPAT). ANAM's metrics evolved from OMPAT's Unified Tri-Service Cognitive Performance Assessment Battery or UTCPAB (23). It has the capability for quantifying cognitive degradation induced by a variety of environmental challenges on astronaut performance ability. S-CAT is a modified version of ANAM, more compatible with NASA needs.

Although the recency of the development of S-CAT has precluded testing its sensitivity to a number of stressors, its similarity to ANAM suggests it will also be sensitive to cognitively debilitating effects of toxic substances and CNS injuries. The purpose of the present research was to determine the sensitivity of S-CAT to the more subtle stress of fatigue induced by sleep deprivation.

METHODS

Participants were 16 male, military officers between the ages of 30-40 (average age 33.3 years). Their average number of flight hours was 2,761 hours (range 280-5000 hours). One of the reasons military pilots were selected as subjects was because they were considered the most comparable to NASA astronauts. Subjects reported normal sleep times (approximately between the hours of 2200-0700) and duration (between 7-8 hours) and reported no unusual sleep patterns. None of the subjects consumed excessive caffeine nor were any using prescription medication. There were two groups tested, each consisting of eight pilots. Group one was tested in September and Group two in October of 1998. All subjects signed consent forms approved by the Advisory Committee for Human Experimentation at Brooks Air Force Base. Subjects were compensated $1,200 for their participation in the study.

All subjects performed 10 repetitions of each cognitive task battery during training on the Wednesday and Thursday before the test began on Thursday evening at 1700 hours. All subjects were confined to the Chronobiology and Sleep Laboratory at Brooks Air Force Base during the 8 hours on Wednesday and 6-hours on Thursday comprising 14 hours of training. Subjects were required to be in bed at 2200 on Tuesday and Wednesday, to be awake by 0600 and to report to the testing facility at 0800 on Wednesday and Thursday of the test week. Actigraph data indicated that 14 subjects complied with the regimen (actigraphs from the remaining two subjects malfunctioned). The testing sessions allowed two circadian performance nadirs to be sampled between 2400-0600 on Friday and 2400-0400 on Saturday of the test week. Subjects were awake at 0600 on Thursday and not allowed sleep until 0400 Saturday. This allowed for a total sleep deprivation time of 46 hours before the opportunity for a short nap.

All subjects were given an opportunity for a nap near the end of the experimental session. At random, half of the subjects were allowed a 4-hour nap and half were allowed a 6-hour nap. Half of the subjects in each of the two nap groups were allowed to sleep in individual rooms of the sleep facility. These rooms had beds, were sound and light attenuated and had private toilets. The other half of the subjects took their naps in a common room on bunks in which external light and noise were also attenuated. All subjects were provided clean sheets, blankets and pillows. The assignment of either sleeping in the individual room or sleeping in the common room was random so as to minimize the impact of utilizing this additional sleeping space in the sleep facility. No restrictions were placed on how the subjects slept and they were not observed during sleep. Evaluation of the 13 of 16 actigraphs whose data were successfully recorded indicated that all subjects slept the entire nap period allotted.

After awakening from their naps, all subjects performed an additional two hours of the computer tasks after which they were released. Throughout the study, during each hour awake, there was 40-45 minutes of testing followed by a 15-20 minute break during which food and social interaction occurred. The subjects were monitored by at least two investigators the entire time to ensure no sleeping occurred. The S-CAT test was not given after 2300 on Friday, corresponding to 41 hours of sleep deprivation, since there were other tests administered during the remaining time period.

There were five test batteries used throughout the study. Table 1 show the abbreviations used in this report, the names and associated tests for each of the test batteries used. As suggested by Table 1, F-PASS is a desktop computer based F-16 flight simulator with operationally relevant mission scenarios. Participants are challenged to complete a bombing mission and to maintain heading, altitude and airspeed using a head up display. The test utilizes a joystick throttle and foot operated rudder controls.

S-CAT consists of five tests. The Code Substitution test has two versions, one with a key in which symbols are paired with numbers and a test symbol requires a look-up identification with the appropriate number. In a second version of this test, only the symbol is shown and memory of the appropriate number must be used to make the correct response. In the Continuous Processing test, a number must be identified as same or different with the immediately preceding number. Mathematical Reasoning requires adding a string of numbers and the response requires identifying if the sum is greater or less than five. Finally, in Matching to Sample, two checkerboard patterns must be compared to a sample box as the same or different.

The PAWS battery was created to test an astronaut's cognitive performance ability onboard space shuttle flights (13). The Critical Tracking test required keeping a cursor in the center of the screen while it became increasingly more difficult to do so. The Directed Attention test required switching from one task (Manikin, spatial reasoning) to another (Mathematical Processing, addition) at the command of an arrow.

The BI test was a version of a test battery used in several long-duration sleep-deprivation studies (3). It involved selecting one of four keyboard choices depending on which corresponding display panel illuminated. Finally, the Visual Search task involved finding multiple white letter F's in a 4x4 matrix of similar letters (I, T, E; difficult search condition) or multiple white F's in a 4x4 matrix of different letters (0, C, Q; simple search condition).

Table 1. Abbreviations for the test batteries used in the study and their individual tests.

F-PASS	Flight Performance Assessment Simulation System
	1.) Identify Enemy Radar Blips
	2.) Situational Awareness Response Time and Accuracy
	3.) Bombing Accuracy
	4.) Deviations from Flight Path
S-CAT	Spaceflight-Cognitive Assessment Tool
	1.) Code Substitution with Key
	2.) Code Substitution without Key
	3.) Continuous Processing
	4.) Mathematical Reasoning
	5.) Matching to Sample
PAWS	Performance Assessment Workstation
	1.) Unstable (Critical) Tracking
	2.) Directed Attention
BI	Bar Ilan (Rise and Shine Test)
	1.) 4 Choice Reaction Time
VS	Visual Search
	1.) Easy Disjunctive Search Trials
	2.) Difficult Disjunctive Search Trials

Oral temperatures, subjective sleepiness, as measured by the Stanford Sleepiness Scale (30), fatigue and effort self-ratings were collected at regular hourly intervals throughout the testing phase of the study. Wrist actigraphs were worn during the testing phase and for at least two days post testing. The F-PASS, the actigraph data and the temperature data will be presented in another report.

Table 2 shows the approximate times each of the test batteries occurred in the 3-hour blocks during the testing phase of the study. Some of the tests were taken 2 and 3 times within a 3-hour block, as indicated in Table 2.

Table 2. Start Times and the Battery Administered for Each 3-Hour Block during the Experimental Session

	Test Battery				
Time	FPASS	S-CAT	PAWS	BI	VS
1700	xxx	x	x	x	x
2000	xxx		x		x
2300	xxx	x	x	x	x
0200	xxx		xx		x
0500	xxx	x	xx	x	x
0800	xxx		xx		x
1100	xxx	x	xx	x	x
1400	xxx		xx		x
1700	xxx	x	xx	x	x
2000	xxx		xx		x
2300	xxx	x	xx	x	x
0200	xxx		xx		x
0400	NAP phase				
0800	xx		x		x
1100	xx		x		x

Note. In the column beneath each battery, xx or xxx indicated that the tests were taken two or three times in the associated 3-hour block.

For all the tests used, data analyses focused on response time and accuracy, either number correct or percent correct. For response time variables, times less than 200 ms were discarded as too fast to be cognitive responses. Univariate analysis of variance (ANOVA) for repeated measures was used to determine if a main effect for testing time (trial) occurred. Mauchly's test was used to evaluate the assumption of sphericity of the ANOVA covariance matrix. When the test was significant, the Huynh-Feldt adjustment was applied to the ANOVA degrees of freedom. Subsequent post-hoc tests (Student's paired t-tests) were used to ascertain significant time (trial) differences from the baseline sample (the first occurrence of the test during the testing phase, usually 1700 Thursday). All participants began their nap at 0400; half of the participants took a 4-hour nap and began their last session at 0830; the remaining half took a 6-hour nap and began their last session at 1030. ANOVAs (and post-hoc t-tests) were used to compare post-nap, pre-nap and baseline (Day 1 at 1700) performances, and to determine whether post-nap performance was dependent on the nap length (i.e., nap group by time interaction). A probability level of 0.05 was used to ascertain significance for all statistical tests.

RESULTS

All 16 of the subjects completed the study. Figure 1 show the mean Stanford Sleepiness Scores, which indicates that the sleep depravation caused the participants to experience fatigue. A score of 7 is maximally sleepy on this scale. All data are shown on this and all subsequent graphs as either ± the standard error of the mean (SEM). As indicated in Figure 1, subjects reported more sleepiness after 0400 on Day 1 (25 hours awake) through 0400 on Day 3 (46 hours awake) compared with baseline. Both the 4-hour nap group and the 6-hour nap group reported less sleepiness after their nap relative to the 46-hour awake sample, as shown in Figure 1. The 4- and 6-hour naps appeared to reduce sleepiness about equally.

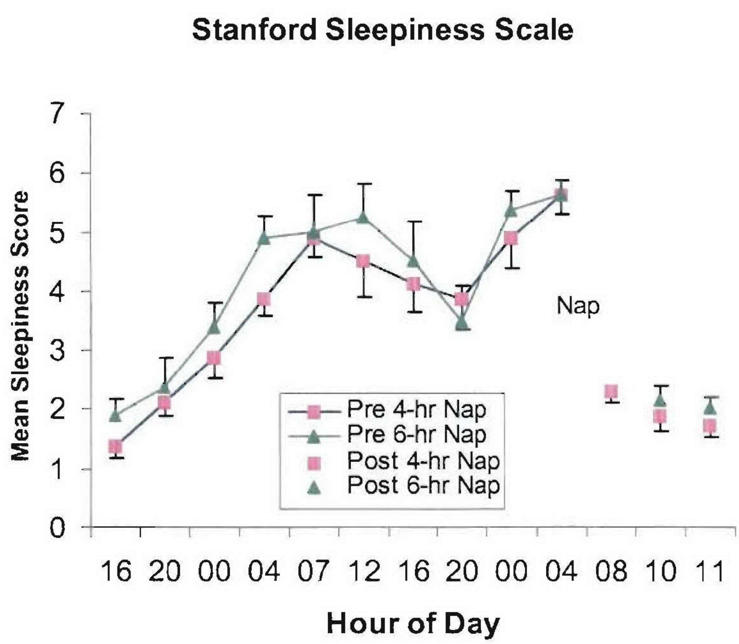

Figure 1. This figure shows the Stanford Sleepiness Scores across all hours of the study for both the 4- and 6-hour nap groups. For this and all subsequent figures, the data are shown +/- the Standard Error of the Mean (SEM).

All of the cognitive test batteries demonstrated significant fatigue effects with the exception of the 4 choice reaction time, the only test used from the Bar-Ilan battery. The S-CAT battery identified fatigue effects on three of the five tests. With regard to response time, Figure 2 shows that the time awake effect was significant for the Match to Sample test (MSP) ($F(5,70) = 4.79$; $p=0.001$) at 0500 hours ($p=0.02$) and 1100 hours ($p=0.009$) and the Math Reasoning test ($F(5,70) = 9.13$; $p<0.0001$) also at 0500 hours ($p=0.02$) and 1100 hours ($p=0.03$), and additionally at 2300 hours ($p=0.03$). Neither of the Code Substitution tests (with or without the key available) nor the Continuous Processing response time data were sensitive to time awake.

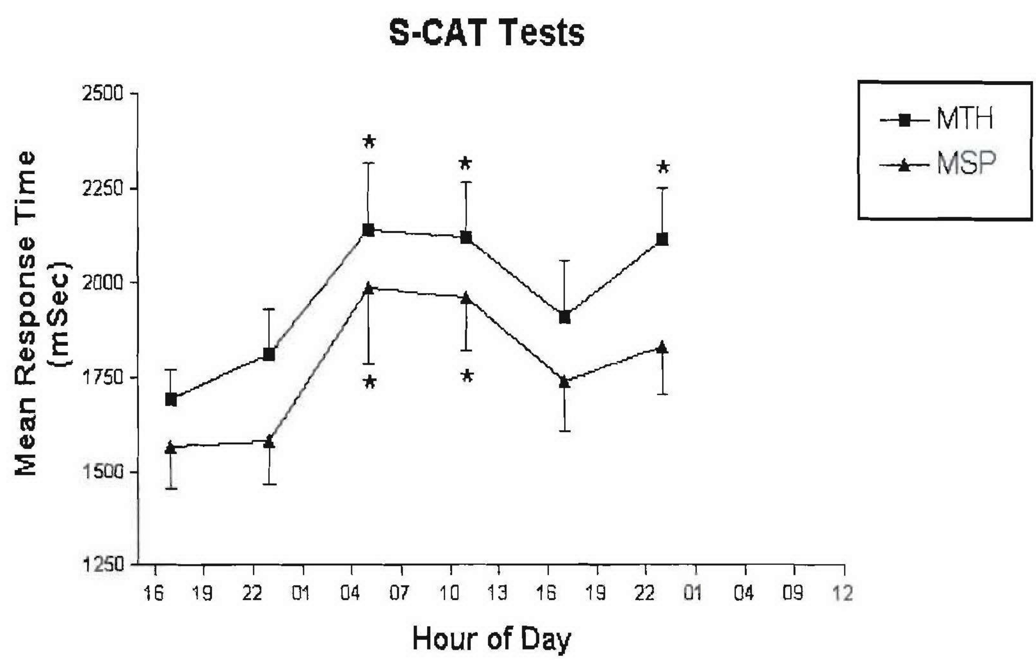

Figure 2. Mean response time data for the Math (MTH) and the Match to Sample (MSP) tests from the SCAT battery are shown at the hours where they were sampled during the study. As in succeeding figures, an asterisk (*) indicates time points significantly different from baseline (p<0.05).

Both the Continuous Processing (CR) test ($F(5,60) = 20.15$; $p<0.0001$) and the Match to Sample (MSP) test ($F(5,70) = 14.45$; $p<0.0001$), unlike any other S-CAT test, showed a significant main effect for percent correct. For CR, these effects occurred at the 0500 ($p=0.015$) and the 1100 ($p=0.003$) time points as shown in Figure 3. For the MSP, the effect occurred at 1100 ($p<0.001$). The greatest degradation of accuracy was evidenced on CR at the 1100 sample with a loss of more than 15% from the baseline sample.

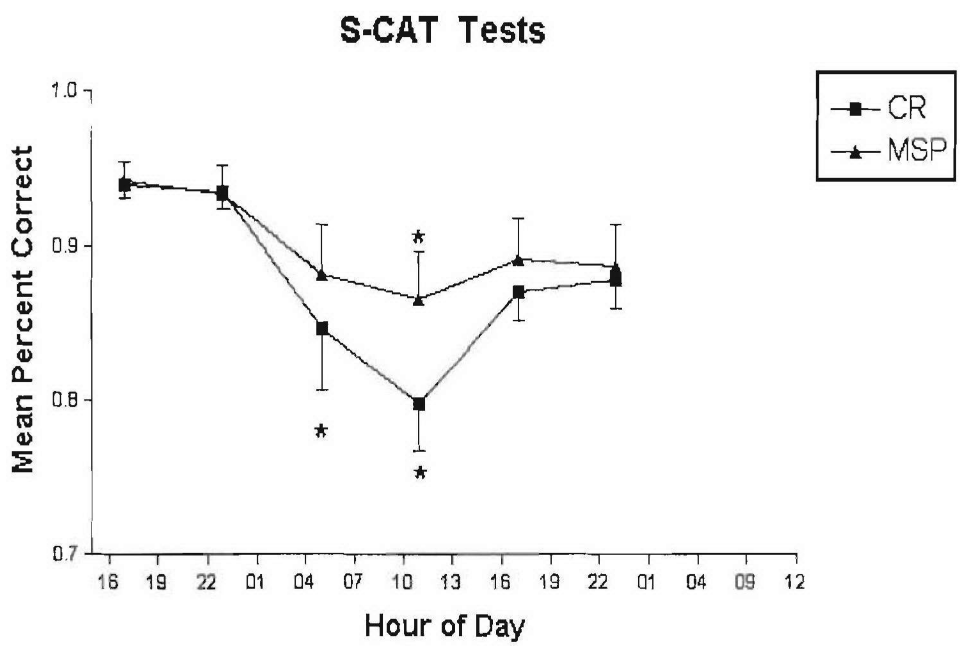

Figure 3. Percent correct data for the Continuous Recognition (CR) and the MSP tests from the SCAT battery.

The Directed Attention task of the PAWS battery, in particular, the response time for the Manikin test, also demonstrated significant effects of time awake ($F(8, 91_{HF\ adjusted}) = 5.31$, $p<0.001$) as shown in Figure 4. The times affected were revealed by post hoc analysis ($p<0.05$) to be on Day 2 at 0800, at 1400, and at all times thereafter except at

1500. These times corresponded to 26, 32, 35 hours awake and beyond. Accuracy scores for the Manikin test were not significantly affected.

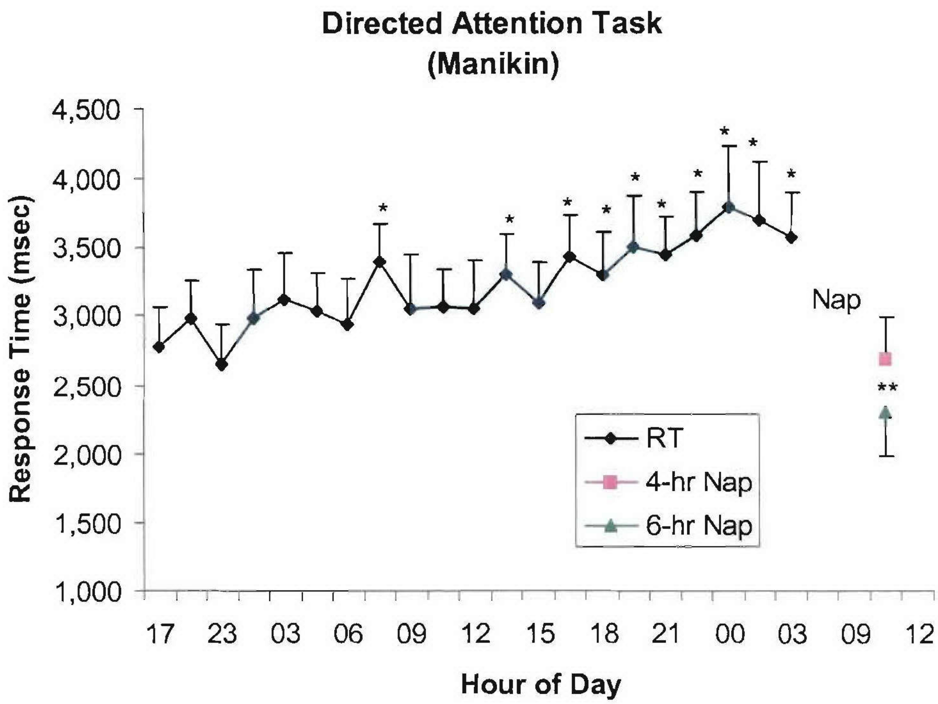

Figure 4. Mean response time data for the Manikin part of the Directed Attention task of the PAWS battery. Data after the nap are additionally shown for the 4-hour and the 6-hour nap group. As in succeeding figures, an asterisk (*) indicates time points significantly different from baseline (p<0.05) and double asterisks (**) indicate difference from pre-nap sample point (p<0.05).

To assess the impact of naps on performance, the post-nap data points for each group at 1100 (after the 6-hr nap) were evaluated against their pre-nap and baseline scores. There was a significant effect for Trial ($F(1,17_{\text{HF adjusted}}) = 10.46$, $p=0.003$), but Nap Groups did not differ nor did they interact with Trial. Post-hoc tests revealed that the response time for both groups after napping was improved over the sample prior to napping ($p=0.002$, 2.50 vs. 3.55 sec) and actually improved slightly over baseline ($p=0.049$, 2.50 vs. 2.72 sec) as shown in Figure 4.

The other half of the Directed Attention task, Mathematical Processing, also showed sensitivity to the degrading effects of fatigue. Response time was statistically significant ($F(10, 115_{\text{HF adjusted}}) = 2.58$, $p<0.008$), but accuracy was not. Post hoc analysis revealed the times affected were on Day 2 at 0200, 0800, 1700 and 2300 and on Day 3 at 0000, and 0200. These times corresponded to 22, 26, 35, 41, 42 and 44 hours awake as shown in Figure 5.

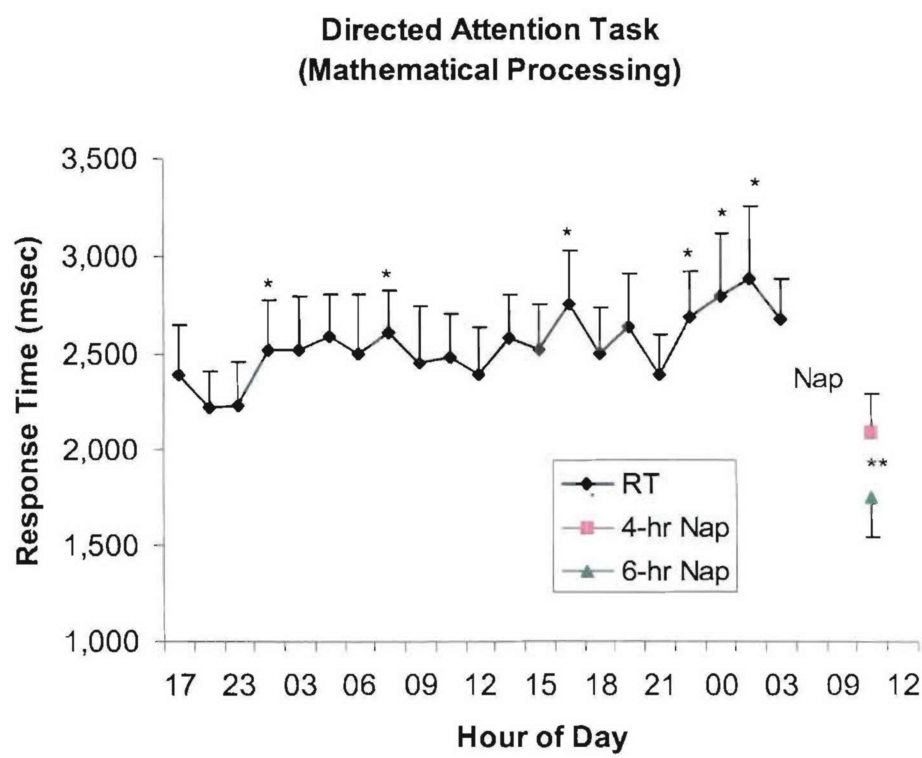

Figure 5. Mean response time data for the Mathematical Processing part of the Directed Attention task. Data after the nap are additionally shown for the 4-hour and the 6-hour nap group.

Similar to the results for the Manikin Task, the Mathematical Processing Task, showed a significant effect comparing baseline, pre-nap, and post-nap samples at 1100 (after the 6-hr nap), $p=0.001$. Again the Nap Groups did not differ nor did they interact with Trial.

Figure 5 shows that the combined response time for both groups after napping was improved over the sample immediately prior to napping ($p=0.001$, 1.92 vs. 2.75 sec) and again improved over baseline ($p=0.002$, 1.92 vs. 2.37 sec).

The other PAWS test used in the study was Unstable Tracking. Both the mean lambda ($F(16,157_{\text{HF adjusted}}) = 3.17$, $p<0.001$) and the maximum lambda ($F(19,188_{\text{HF adjusted}}) = 2.47$, $p<0.001$) scores were sensitive to fatigue in the current study. Figure 6 demonstrates that mean lambda recorded an overall fatigue effect across trials, and was significant at the 0900 through 1800 time points on Day 2 corresponding to 27 through 37 hours awake. Maximum lambda also showed significant deviations from baseline on Day 2 at 0900, 1100, 1400, 1500, and 2000 hours corresponding to 27, 29, 32, 34, and 39 hours awake. Unfortunately, the post-nap tracking data were corrupted and could not be analyzed.

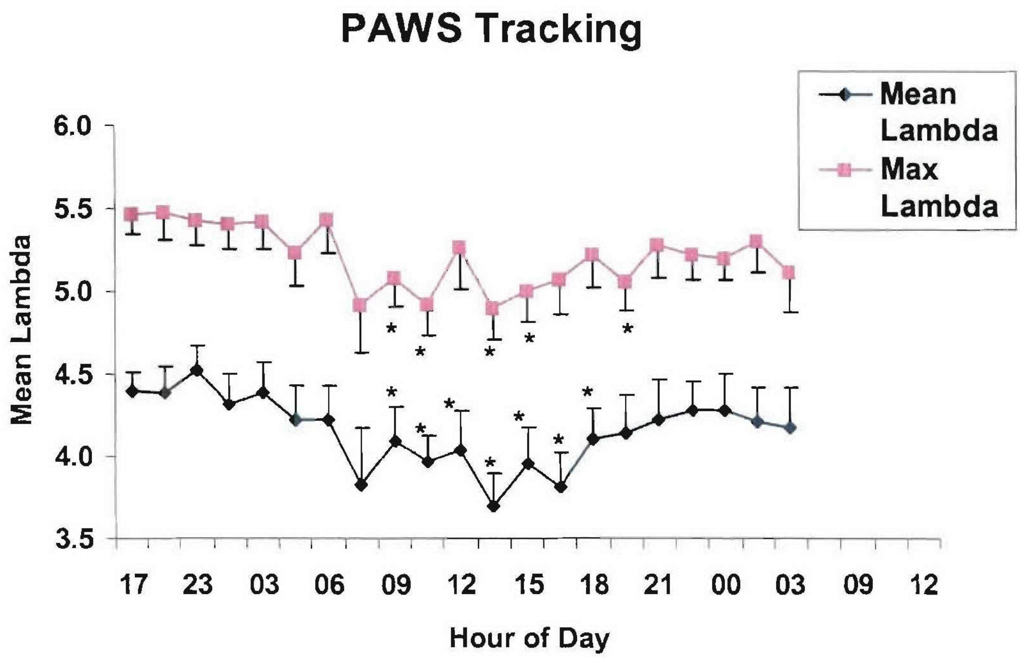

Figure 6. The mean and maximum lambda data for the Unstable Tracking test from the PAWS battery.

Both the difficult and, to a lesser extent, the easy trials of the Visual Search task were affected by time awake ($F(6, 84_{\text{HF adjusted}}) = 7.15$, $p<0.001$ and $F(9, 121_{\text{HF adjusted}}) = 3.66$, $p<0.001$, respectively) as shown by response time in Figure 7. For the difficult trials this effect was observed at all times from Day 1 at 2300 through Day 3 prior to the nap ($p<0.05$). The degraded performance started after only 17 hours awake. Degraded performance for the easy trials was observed starting on Day 2 at 0500, 0800 and 1400 ($p<0.05$) corresponding to 23, 26, and 32 hours awake as shown in Figure 7.

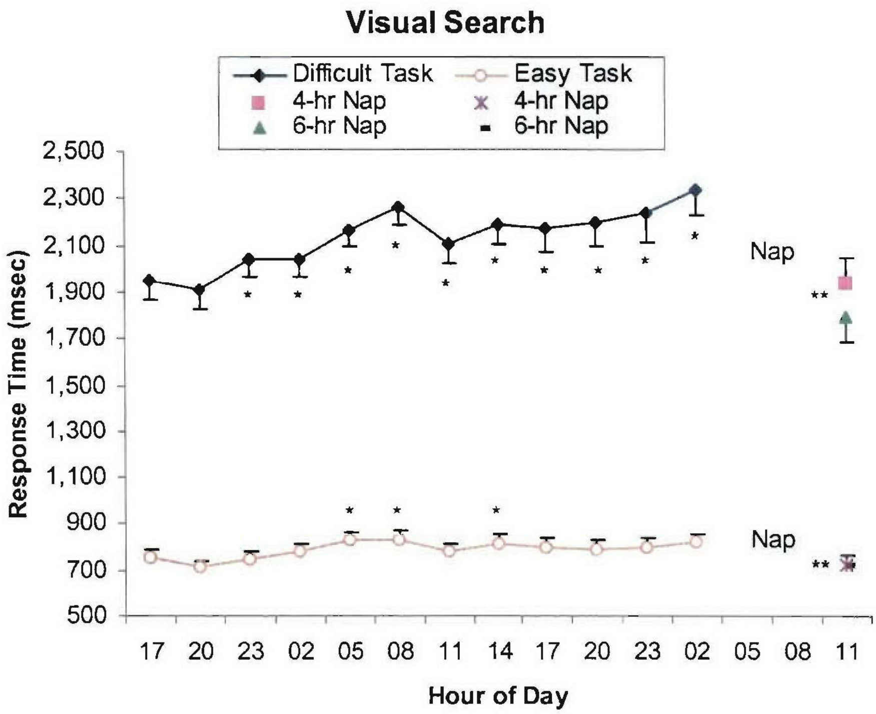

Figure 7. Mean response time data for the difficult and easy trials of the Visual Search task. Data for the 4-hour and the 6-hour nap group are shown after the nap.

Both the difficult and easy trials also were sensitive ($p<0.001$ and $p=0.005$, respectively) to naps as shown in Figure 7. The sample obtained immediately after the nap was significantly improved from the sample immediately before the nap for both groups ($p<0.001$ and $p=0.004$, respectively). Neither Nap Group nor its interaction with trial was significant for either difficult or easy trials.

DISCUSSION

The results indicate that the Continuous Processing test, the Matching to Sample test and the Math Reasoning tests of the S-CAT battery are sensitive to fatigue comparable to other established performance tests of fatigue, including some that have evaluated shuttle astronaut performance in the past (13). Some of the S-CAT tests were not sensitive to fatigue, specifically the Code Substitution tasks with and without a key and Continuous Processing. Surprisingly, the Bar-Ilan test was not affected by the 46 hours of sleep deprivation. However, only one of the tests in this normally, fatigue sensitive battery (3) was used, the 4 Choice Reaction Time. It seems possible that the others might have shown sensitivity if time had permitted their inclusion.

Many of the performance test measures of the fatigue insensitive tests showed trends similar to the fatigue sensitive tests. In these cases, the test measures usually demonstrated larger variances implying that greater power with more subjects may have resulted in statistical significance. Tests not showing fatigue sensitivity may not have been affected because of a test specific selectivity in brain location that might be unsusceptible to sleep deprivation. Glucose metabolism studies suggest that fatigue induced decrements in positron emission can be found in prefrontal and inferior parietal cortices and in thalamic sites (38). Perhaps the fatigue insensitive tests were too motivating. It has been shown that less motivating tasks are more affected by fatigue (6, 20). As well, simplicity of the task, like simple reaction time, can be profoundly affected by sleep loss (12). Self-paced tests are well known to be less affected than are investigator-paced tests (22, 7). Measures of accuracy are usually not as affected by fatigue as are reaction time metrics since a speed, accuracy trade-off is often observed on well established performance tests (1).

In this study the subjects received either a 4-hour nap or a 6-hour nap at 0400 after 46 hours awake. Some of the tests were taken after awakening from the nap. Most notably, Figures 4, 5, and 7 demonstrated a significant improvement over the score obtained immediately before the nap, although nap lengths (i.e. 4-hours or 6-hours) were not significantly different. Other studies have found similar immediate effects of naps. In a field study for example, a 4-hour nap was sufficient to improve performance scores after 90 hours awake (19). Two-hour naps were found to improve performance after 45 hours of wakefulness (31). Although the 4- and 6-hour naps appeared to return performance to rested baseline levels, other factors may have been the cause. Performance recovery may have resulted from: subjects anticipating the end of the experiment or subjects experiencing a release from task fatigue or boredom since tests were not administered while they slept. Actigraphic data showed no differences in sleep duration or quality between those who napped in the individual rooms and those whose nap occurred in the common room. The two groups also showed no differences in post-nap cognitive performance.

The study found robust fatigue effects on performance with S-CAT, especially when compared to traditional tests. It is likely that S-CAT data would identify an astronaut impaired by fatigue and who may not subjectively be aware of their condition.

Variables that affect a person's vulnerability to fatigue are important to identify for sustained operations. Comparing the data of this study using pilots with data from the WRAIR 72-hour sleep deprivation study (21, 39) using non-pilot subjects, we found that pilots appear to be less vulnerable to the affects of fatigue. Comparing the mean of the combined data values from the cognitive tests between 16 and 46 hours awake, pilots are at approximately 84% of their baseline while the WRAIR subjects were at approximately 74.8% of their baseline. Since there are wide differences in vulnerability to fatigue (41), a difference of over 9% may indicate that pilots are in the less vulnerable tail of the normal distribution.

Future research should examine the test sensitivity of S-CAT to other stressors and compare these results with those of fatigue. The next stressor should be that induced by alcohol impairment. Dawson (10) found that 20-25 hours of wakefulness produced impairment similar to a blood alcohol level of 0.1%. Alcohol impairment is well known and easily demonstrated. There are some that suggest that alcohol impairment may provide a simple way to demonstrate impairment from other psychoactive stressors (18, 37) in much the same way that other stressors degrade performance like fatigue (e.g., heat stress) (9). The present results would suggest that the Continuous Recognition, Matching to Sample and Math Reasoning tests of the SCAT battery would also be sensitive to alcohol.

REFERENCES

1. Angus, R.G. & Heslegrave, R.J. Effects of sleep and sustained cognitive performance during a command and control simulation, *Behavioral Research Methods, Instruments and Computers, 17*, 1985, 55-67.

2. Akerstedt, T. & Gillberg, M. Subjective and objective sleepiness in the active individual. *International Journal of Neuroscience, 52*, 1990, 29-37.

3. Babkoff, H., Mikulincer, M., Caspy, T., Kempinski, D. & Sing, H. The topology of performance curves during 72 hours of sleep loss: A memory and search task. *The Quarterly Journal of Experimental Psychology, 324*, 1988, 737-356.

4. Bleiberg, J. Halpern, E.L., Reeves, D., Daniel, J.C., Future directions for the neuropsychological assessment of sports concussion. *J. Head Trauma Rehabilitation, 12(2)*, 1998, 36-44.

5. Bleiberg, J. Garmoe, W.S., Halpern, E.L., Reeves, D.L. & Nadler, J.D. Consistency of within day and across day performance after mild brain injury. *Neuropsychiatry and Behavioral Neurology, Oct, 10(4)*, 1997, 247-53.

6. Bonnett, M.H. Sleep deprivation, In M.H. Kryger, T. Rogh & W.C. Dement (Eds) *Principles and Practice of Sleep Medicine* (2nd edition), Philadelphia, WB.Saunders, 1994.

7. Broadbent, D.E. Noise, paced performance and vigilance tasks. *British Journal of Psychology, 44*, 1953, 295-303.

8. Brown, I.D., Tickner, A.H. & Simmons, D.C. Effect of prolonged driving on overtaking criteria. *Ergonomics, 13*, 1970, 239-242.

9. Bursill, A.E. The restriction of peripheral vision during exposure to hot and humid conditions. *Quarterly Journal of Experimental Psychology, 10*, 1958, 113-129.

10. Dawson, D. & Reid, K. Fatigue, alcohol and performance impairment. *Nature, 388*, 1997, 235.

11. Dinges, D.F. Performance effects of fatigue, *Fatigue Symposium Proceedings. National Transportation Safety Board.* 1995.

12. Dinges, D.F., Whitehouse, W.G., Orne, E.C. & Orne, M.T., The benefits of a nap during prolonged work and wakefulness. *Work and Stress, 2*, 1988, 139-153.

13. Eddy, D.R., Schiflett, S.G., Schlegel, R.E. & Shehab, R.L., Cognitive performance aboard the life and microgravity spacelab, *Acta Astronautica, 43*, 1998, 192-210.

14. Fiorica, V., Higgins, E.A., Iampietro, P.F., Lategola, M.T. & Davis, Q.W. Physiological responses of man during sleep deprivation. *Journal of Applied Physiology, 24(2)*, 1968, 169-175.

15. Gastaldo, E., Reeves, D. Levinson, D. & Wenger C.D., *ANAM Normative Data: USMC-1995 Hyponatremia Outbreak Studies*, National Cognitive Recovery Foundation Technical Report, 1997.

16. Gillberg, M., Kecklund, G. & Akerstedt, T. Relations between performance and subjective ratings of sleepiness during a night awake. *Sleep, 17(3)*, 1994, 236-41.

17. Hamilton, P., Wilkinson, R.T. & Edwards, R.S. A study of four days partial sleep deprivation. In W.P Colquhoun (Ed.) *Aspects of Human Efficiency*, 1972, 101-133.

18. Heishman, S.J., Stitzer, M.L. & Bigelow, G.E. Alcohol and marijuana: Comparative dose effect profiles in humans, *Pharmacology, Biochemistry and Behaviour, 31*, 1989, 649-655.

19. Haslem, D.R. Sleep loss, recovery sleep and military performance. *Ergonomics, 25(2)*, 1982, p 163-178.

20. Horne, J.A. & Pettitt, A.N., High incentive effects on vigilance performance during 72 hours of total sleep deprivation. *Acta Psychologica, 58*, 1985, 123-139.

21. Hursh, S.R., Redmond, D.P., Johnson, M.L., Thorne, D.R., Belenky, G, Balkin, T.J., Storm, W.F., Miller, J.C., Eddy, D.R. Fatigue models for applied research in warfighting. *Aviat Space Environ Med*, 75(3, Suppl.), 2004, A44–53.

22. Johnson, L.C. & Naitoh, P. *The operational consequences of sleep deprivation and sleep deficit*. AGARDograph #193, 1974, 1-43.

23. Kane, R.L. & Kay G.G., Computerized tests in Neuropsychology: A review of tests and batteries. *Neuropsychological Review, 13*, 1992, pp 1-117

24. Levinson, D.M., Reeves, D.L., Wild, M.R., & Lewandowski, A.G. Classifying level of neurocognitive impairment in individuals with Acquired Brain Injury, *Archives of Clinical Neuropsychology, 13(1)*, 1998, p 73

25. Levinson, D.M. & Reeves, D.L. Monitoring recovery from traumatic brain injury using automated neuropsychological assessment metrics. *Archives of Clinical Neuropsychology, 12(2)*, 1997, 155-166.

26. Levinson, D.M. & Reeves, D.L., *Automated Neuropsychological Assessment Metrics (ANAM): ANAM V1.0 Normative Data*, NCRF-TR-94-01, San Diego, CA, National Cognitive Recovery Foundation, 1994.

27. Linde, L. & Bergstrom, M. The effect of one night without sleep on problem solving and immediate recall. *Psychological Research, 54(2)*, 1992, 127-36.

28. Manzey, D., Lorenz, B., Schiewe, A., Finell, G., & Thiele, G., Behavioral aspects of human adaptation to space: analyses of cognitive and psychomotor performance in space during an 8-day space mission. *Clinical Investigator, 71*, 1993, 725-731.

29. Mohler, S.R. Fatigue in aviation activities, *Aviation Medicine, 37*, 1966, 722-732.

30. Monk TH. *Sleep, Sleepiness and Performance*. Chichester: John Wiley & Sons, 1991.

31. Naitoh, P. Circadian cycles and restorative powers of naps. In *Variations in Work-Sleep Schedules: Effects on Health and Performance Vol. 7.* L.C. Hohnson, D.I Tepas, W.P Colquhoun and M.J. Colligan. NY Spectrum Press. 1981, 553-580

32. Rahill, A.A., Weiss, B. Morrow, P.E., Frampton, M.W., Cox, C., Gibb, R. Gelein, R. Speers, D. & Utell, M.J. Human performance during exposure to toluene. *Aviation Space and Environmental Medicine, 67(7)*, 1996, 640-647.

33. Reeves, D., Kane, R., Winter, K., Raynsfore, K. & Pancella, T., *Automated Neuropsychological Assessment Metrics (ANAM): Test administrator's guide Version 1.0*, St. Louis, Missouri Institute of Mental Health, 1993.

34. Reeves, D., Gamache, G., Levinson, D., & Bidiouk, P. Neuropsychological and physical assessments: Ten+ years after the Chernobyl nuclear accident. *Archives of Clinical Neuropsychology, 13(1)*, 1998, 123

35. Roth, T., Roehrs, T.A., Carskadon, M.A. & Dement, W.C., Daytime sleepiness and alertness. In M.H. Krygher, T. Roth & WC Dement (Eds.) *Principles and Practices of Sleep Medicine*, WB Saunders Co. 1994.

36. Shingledecker, C.A. & Holding, D.H., Risk and effort measure of fatigue, *Journal of Motor Behavior, 6*, 1974, 17-25.

37. Tharper, P., Zacny, J.P., Thompson, W. & Apfelbaum, J.L. Using alcohol as a standard to assess the degree of impairment induced by sedative and analgesic drugs used in ambulatory surgery. *Anesthesiology, 82(1)*, 1995, 53-59.

38. Thomas, M.L., Sing, H.C. Belenky, G., et al. Cerebral glucose utilization during task performance and prolonged sleep loss. *Journal of Cerebral Blood Flow and Metabolism, 13(1)*, 1993, S531.

39. Thorne, D.R., Genser, S., Sing, H., Hegge, F.. Plumbing human performance limits during 72 hours of high task load. *Proceedings of the 24th DRG seminar on the human as a limiting element in military systems*, Defense and Civil Institute of Environmental Medicine, 1983, 17-40, Toronto, Canada.

40. Tilley, A.J. & Wilkinson, R.T. The effects of a restricted sleep regime on the composition of sleep and on performance. *Psychophysiology, 21*, 1984, 406-412.

41. Van Dongen HP, Maislin G, & Dinges DF. Dealing with inter-individual differences in the temporal dynamics of fatigue and performance: importance and techniques. *Aviat Space Environ Med.*, *75*(3 Suppl), 2004, A147-54.